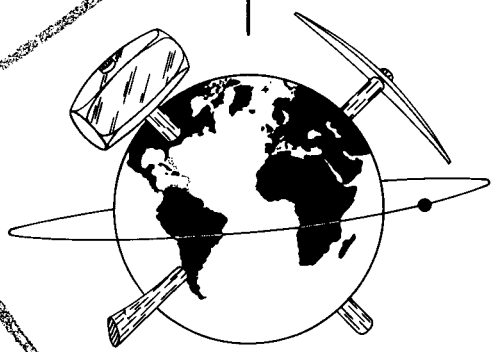
UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES



TWIN CITIES MINING RESEARCH CENTER

Thomas C. Atchison, Research Director

NASA Contract R-09-040-001

MULTIDISCIPLINARY RESEARCH LEADING TO UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Quarterly Status Report
July 1, 1971 to October 1, 1971

U.S. Bureau of Mines NASA Program of Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

QUARTERLY STATUS REPORT July 1, 1971 to October 1, 1971

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STATUS REPORT FIRST QUARTER FISCAL YEAR 1972

U.S. Bureau of Mines NASA Program of Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

October 1, 1971

Task title: Background analysis and coordination
Investigator: David E. Fogelson, Program Manager
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota
Date begun: April 1965 To be completed: Continuing

Personnel: David E. Fogelson, Supervisory Geophysicist
Other Bureau personnel, as assigned

PROGRESS REPORT

Objective

The objective of the program is to help provide basic scientific and engineering knowledge needed to use extraterrestrial mineral resources in support of future space missions. Under this component, background and supporting studies and coordinating and liaison activities for the program are carried out.

Progress During the First Quarter

The initial phase of the Bureau's program beginning with fiscal year 1966 consisted of a period of background study and task definition carried out by a small interdisciplinary core group at the Twin Cities Mining Research Center. The second phase, completed by the end of fiscal year 1969, comprised 16 closely related research tasks conducted at seven bureau research centers. Results of these tasks were presented in the annual status reports to NASA for fiscal years 1967, 1968, and 1969 and published in Bureau and NASA reports and scientific journals. The present phase of the program began in fiscal year 1970 and was planned for completion at the end of fiscal year 1971. Funding cutbacks and experimental problems have postponed the planned completion date until the end of fiscal year 1972. This phase represents an extension and refinement of some of the previous research tasks with major emphasis on the more basic studies of material properties and behavior in simulated lunar environment. Three tasks are being conducted at the Twin Cities Mining Research Center, one at the Pittsburgh Mining and Safety Research Center, and one at the Spokane Mining Research Center. During the past quarter, recently published information on Apollo's 14 and 15 was reviewed, evaluated, and distributed to the task investigators.

Arrangements were made with Dr. Jack Green to study basalt casting as a means of utilizing lunar rocks in the construction of manned bases. This study will include the casting of raw basalt samples at three different rates of cooling (one day, one week, one month); petrographic studies of the original sample material and products obtained; casting of basalt with 10 percent calcium bicarbonate and 10 percent potassium bicarbonate at three annealing rates; and differential thermal analyses of all start and finish products. Powdered tholeiitic basalt samples are being supplied by the Twin Cities Mining Research Center.

A proposal for continuing the Bureau's program into fiscal years 1973 and 1974 is being prepared.

Status of Manuscripts

Electrowinning of Oxygen From Silicate Rocks by Donald G. Kesterke was published as Bureau of Mines Report of Investigations No. 7587.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1972

Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Surface properties of rocks in simulated lunar environment
Investigator: Wallace W. Roepke, Project Leader
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota
Date begun: April 1966 To be completed: June 1972

Personnel: William H. Engelmann, Supervisory Research Chemist
Wallace W. Roepke, Principal Vacuum Specialist
Bradley V. Johnson, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this project is to study the surface properties of rocks and minerals in a simulated lunar environment. The study encompasses friction between ultraclean mineral-mineral pairs, drilling of rock, and vane shear tests, all performed in ultrahigh vacuum.

Progress During the First Quarter

Ultrahigh Vacuum Friction Studies

Valid friction test results have been obtained for eight test pairs in UHV. A sufficient number of tests have been run in each set to allow good statistical handling of the data. Two of the eight test pairs were reference samples of stainless steel (type 304) with one polished to a 5 μm finish and the other lapped to 37 μm. The other samples were quartz, basalt, labradorite, magnetite, feldspar, and andesine in monzonite porphyry. All of the rock and mineral samples were lapped to a 37 μm finish. These results show a 125 to 355 percent increase for the kinetic coefficient of friction (μ_k) in UHV over those results for tests in atmosphere reported in the fiscal year 1971 Annual Status Report. These results were obtained using only the bakeout cycle and pumpdown of the system as the cleaning mechanism. All results were obtained at a base pressure of 2×10^{-10} torr or lower. Further increases are anticipated for these materials when laser cleaning is used and the sample test temperature is increased to 135° C to simulate lunar daytime temperature.

Ultrahigh Vacuum Vane Shear Studies

Further analysis of the vane shear test data in UHV indicates that there is some increase in shear strength under UHV conditions over that of atmospheric conditions. Data analysis is continuing and a manuscript

for a Report of Investigations (RI) has been started. No further testing is planned at this time and the vane shear apparatus has been removed from the drilling rig. The experimental apparatus will be maintained in working condition to allow further use with lunar materials if necessary at a later date.

Ultrahigh Vacuum Drilling

The UHV drilling rig has been used for a considerable period of time as the main supporting frame for the vane shear work. Because dust generated by the vane shear testing may have gotten into the bearing areas, the system is being refurbished for the drilling tests. It is expected that drilling will be started during the next quarter depending on pumpdown time.

Personnel Changes

James R. Blair was reassigned from NASA surface properties studies to NASA thermal properties studies, 100 percent. Bradley V. Johnson has been assigned, 60 percent, to NASA surface properties studies for this fiscal year.

Status of Manuscripts

The patent, "Electron Suppressor Grid for a Mass Spectrometer," by W. W. Roepke and K. G. Pung has been filed and assigned No. MIN-1258/1910.

Suppression of Mass Spectrometer Generated Interference on a Nude Bayard-Alpert Gauge in UHV by W. W. Roepke and K. G. Pung is under preparation as a journal article.

Shear Testing of Simulated Lunar Material in UHV by B. V. Johnson, W. W. Roepke and K. C. Strebig is being prepared to be published as a Bureau of Mines Report of Investigations.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1972

Bureau of Mines NASA Program of Multidisciplinary Research

Task Title: Rock failure processes and strength and elastic properties in simulated lunar environment
Investigator: John O. Atkins, Project Leader
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota
Date Begun: June 1966 To be completed: June 1972

Personnel: S. S. Peng, Mining Engineer
John O. Atkins, Physicist
Stephen D. Anderson, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this project is to study the effect of simulated lunar environment on rock deformation and failure processes at the mesostructural and the microstructural level. The engineering data obtained from simulated lunar rocks under these environmental conditions will assist advance planning of lunar resource utilization.

Progress During the First Quarter

Elevated Temperature Compression Tests in Ultrahigh Vacuum

The compressive study of dacite, basalt, and Duluth Gabbro specimens in UHV at the lunar "day" temperature (135° C) has been completed. Three specimens of each rock type were tested. The dacite and basalt specimens were cored from common directions in their respective blocks. The Duluth Gabbro specimens were cored from the low velocity direction in the Duluth Gabbro block (as determined by the ultrasonic pulsing of an oriented sphere prepared from this block).

The results of these tests were very consistent and will be reported after data reduction has been completed.

Acoustic and Ultrahigh Vacuum Compression Anisotropy Studies

During the second quarter, compressive tests will be made in UHV at room temperature on Duluth Gabbro specimens having low, medium, and high velocity orientations. The specimens for these tests were prepared from the same block as the Duluth Gabbro specimens used in the elevated temperature study. These tests will provide information on the anisotropy of compressive behavior of Duluth Gabbro in UHV and will provide reference data for determining the effect of the lunar "day" temperature on the compressive behavior of Duluth Gabbro in UHV.

Specimens of vesicular basalt and pumice cored from low, medium and high velocity directions of their respective blocks have been prepared. Acoustic measurements will be made on these specimens; and compressive tests in UHV will be initiated during the second quarter.

Fabric Analysis

An analysis of fabric in dunite samples was completed by the Fabric Analysis Laboratory. The orientations of the x, y, and z optical indicatrix axes for 100 olivine grains were determined on a universal stage and were plotted as equal-angle scatter diagrams. These diagrams reveal a preferred orientation of the olivine grains. The orientation of microfractures in dunite were determined both by a universal stage study and by a defect frequency orientation study. Normalized polar defect frequency graphs reveal a preferred orientation of the microcracks. A preliminary examination of these results show a correlation between the symmetry of the dunite fabric and the velocity and relative amplitude symmetries obtained by Bur and Hjelmstad.[1]

During the second quarter a similar fabric study will be made on Duluth Gabbro specimens. After this study is completed, an attempt will be made to correlate the results of the acoustic and fabric studies with the results of the compression study.

1 Icarus (Internat. J. Solar Systems Studies) v. 13, No. 3, Nov. 1970.

Status of Manuscripts

Environmental Effects on Rock Properties by E. R. Podnieks, P. G. Chamberlain, and R. E. Thill has been submitted for publication in the Proceedings of the Tenth Symposium on Rock Mechanics held at the University of Texas in May 1968.

Effect of Moisture and Temperature on the Fracture Morphology of Dacite by R. J. Willard and K. E. Hjelmstad will be published in the Internat. J. of Rock Mech. and Min. Sci., v. 8, 1971.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1972

Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Thermal fragmentation and themophysical and optical properties in simulated lunar environment

Investigator: David P. Lindroth, Project Leader
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota

Date begun: July 1971 To be completed: June 1972

Personnel: Kuppusamy Thirumalai, Supervisory Mining Engineer
David P. Lindroth, Physicist
James Blair, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this work is to study the problems of thermal fragmentation in lunar environment. Through the use of nondestructive testing and remote sensing technology, the thermophysical properties of simulated lunar rocks are to be determined as a function of temperature and pressure over the lunar environment range. A study on the optical properties of absorptance, reflectance, and the absorption coefficient as a function of wavelength and temperature will be made.

Progress During the First Quarter

Emphasis this quarter was placed on system design and modification and sample preparation. The system design and modification is nearly complete and is contingent on the machine shop heliarc welding of the stainless steel parts.

Custom made and mounted Germanium windows were ordered for the system to eliminate the leak problems encountered earlier with the windows fabricated in-house. A window which transmits the visible wavelengths was mounted on the system to aid in alignment of the samples while under ultrahigh vacuum (UHV). Also, a stainless steel screen was mounted inside and at the base of the chamber above the ion pump throat to confine the pump's glow discharge to the pump area and eliminate potential dropping of parts into the ion pump.

To have an independent rough pumping capability and to try and minimize pump down times a foreline has been designed to be an integral part of the system. This foreline (6 in long, 1-1/2 OD tube) contains a sorption pump and UHV valve, a thermocouple gauge, and an up-to-atmosphere valve

for rough pumping. As soon as the machine shop has finished heliarc welding the thermocouple gauge and up-to-atmosphere valve on the foreline, it will be mounted on the UHV system. A Bell and Gossett oil-less vacuum pump was obtained for rough pumping.

Having been plagued for the last six months with various small leaks, which have limited the ultimate pressure to 10^{-6} torr, a flange adapter has been ordered to allow coupling a mass spectrometer head to the UHV system. The mass spectrometer capability will facilitate determination of the leaking areas and identify residual gases in the system.

The gear box, bearing assembly, and gears for driving the multispecimen sample holder have been redesigned to provide more torque and more accurate alignment. The work order for machining and heli arc welding is in the shop awaiting completion.

The sample preparation has been nearly completed. Forty, 19 mm diameter disks, varying from 2 to 8 mm thick, have been cut and polished for each of the following rock types: Duluth Gabbro, dunite, obsidian, granodiorite, and tholeiitic basalt.

Status of Manuscripts

None scheduled.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1972

Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Use of explosives on the moon
Investigator: J. Edmund Hay, Project Leader
Location: Pittsburgh Mining and Safety Research Center
Pittsburgh, Pennsylvania
Date begun: July 1966 To be completed: June 1972

Personnel: Richard W. Watson, Research Physicist
J. Edmund Hay, Research Physicist
Robert M. Swatkis, Physical Science Technician
Joseph Ferrelli, Physical Science Aid

PROGRESS REPORT

Objective

To develop a body of fundamental knowledge relevant to potential problems involved in the application of chemical explosives to mining and related activities on the moon and other extraterrestrial environments.

Progress During the First Quarter

Research efforts were concentrated on resolving the non-reproducible character of the recorded stagnation-pressure-vs-time profiles of the detonation products from a spherical charge of explosive detonated in a vacuum.

Some spurious portions of the signals are apparently due to electrical pickup caused by self-ionization of the detonation products; however, the non-reproducible character of the signals cannot be attributed solely to this source. Experiments comparing the output of several "identical" transducers at the same distance from the charge, or comparing the outputs of the same transducer in replicate firings, failed to show consistency in amplitude or shape; the scatter of even the times of arrival was far greater than instrumental precision could account for.

Other commercial and laboratory-made transducers were tried in an attempt to determine the source of the problem. The signals obtained with other types of piezoelectric transducers were not comparable to those obtained with the original type of transducer due to ringing. The Bureau-developed resistive pressure gages were tried in a bridge configuration with high voltage excitation; the signals obtained were "cleaner" than those obtained with the piezoelectric transducers, but no more reproducible in amplitude

and shape. A transducer design consisting of strain gages in a bridge configuration on a steel diaphragm also gave a non-reproducible response, complicated by poor frequency response and signal features which may represent diaphragm buckling. Signals obtained using four "identical" gages in successive firings at different initial pressures displayed a tendency to become somewhat more reproducible as the initial pressure increased. It appears that the problem may be due in part to differences in the response of supposedly "identical" gages, compounded by some inherent non-uniformity of the detonation products cloud.

Status of Manuscripts

None scheduled.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1972

Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Gravity flow of granular materials
Investigator: David E. Nicholson, Project Leader
Location: Spokane Mining Research Center
Spokane, Washington
Date begun: July 1971 To be completed: January 1974

Personnel: David E. Nicholson, Mining Engineer

PROGRESS REPORT

Objective

To develop an optimizing design program for gravity flow bins and hopper with elastic-plastic finite element methods.

Progress During the First Quarter

The title of the materials handling studies has been changed to reflect the change in emphasis required as a result of the completed research and the funding reduction. The former title was "Effect of Lunar Environment on Behavior of Fine Particles." A paper titled "Gravity Flow of Powder in a Lunar Environment" was presented at the International Powder Technology and Bulk Solids Conference, Harrogate, England, May 12-14, 1971.

The present emphasis will be on the development of computer programs for designing bulk solids bins and hoppers for optimum flow. Three geometric parameters--height of bin, width of orifice and slope of side wall--will be variables, while lunar soil properties and reduced lunar gravity will be specified.

This project will be carried under a graduate fellowship at the University of Utah under the direction of Dr. William G. Pariseau. Total funding is $5,000. A work fellowship agreement has been arranged with Robert Thompson, a mining engineering student at Montana School of Mines, Butte, Montana, who will graduate in February 1972. An application for a mining engineering rating has been prepared for the Civil Service Board, and if approved, the fellowship will be started in the spring quarter at the University of Utah.

Status of Manuscripts

Gravity Flow of Powder in a Lunar Environment, Part I: Testing of Simulated Lunar-Basalt Powder for Gravity Flow by David E. Nicholson published as Bureau of Mines Report of Investigations No. 7543; Part II: Analysis of Flow by William G. Pariseau was presented under a changed title at the International Powder Technology and Bulk Solids Conference, Harrogate, England, May 12-14, 1971, and published as Bureau of Mines Report of Investigations No. 7577.